Joint assessment of the probability characteristics of long-term river runoff and evaporation in today's climate conditions and in the expected changes

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***Abstract*—The possibility of joint assessments of actual and scenario estimates of probability characteristics of long-term river runoff and evaporation was shown. A model in the form of linear shaping filter, which decisions in a statistically stationary mode result in K. Pearson distribution class was used. Visualization of the resulting estimates was given in the form of one-dimensional manifolds, representing probability curves in three dimensions (security, runoff, evaporation). It was shown that selective evaporation value increases as probability of precipitations grows in all climate zones of the Northern and Southern hemispheres.**

***Index Terms*—climate scenario, Fokker–Planck–Kolmogorov equation, probability curves of discharges, probability curves of evaporation.**

I. Introduction

The article [2] shows a methodology for assessing the long-term changes in the probability characteristics of long-term runoff under climate change conditions taking the African continent as the example. It is based on a stationary version of the Fokker–Planck–Kolmogorov equation. The latter is approximated by a system of algebraic equations for the initial moments, with help of which the calculated hydrological characteristics (norm $\overline{Q}$, coefficients of variation *Cv* and skewness *Cs*) are calculated. With their help, according to the tables used in the statistics, we find the ordinates of the probability curves, which are used when calculating the reliability of the designed and operated hydraulic structures.

II. Methods

Currently, probability curves are plotted on the actual observation series. Using the model under consideration allows us to plot these curves based on climate scenarios proposed by the Intergovernmental Panel on Climate Change [3]. The model stationary is determined by the nature of the climate scenarios, which are recommended to be used as 20–30-year statistically equilibrium periods with constant norms of meteorological parameters (precipitation and surface air temperature). It was found [1] that the probability distributions of long-term evaporation series also belong to the Pearson distribution class. This justifies applying to evaporation a model similar to that for the river runoff with a slightly modified interpretation of its parameters. It is based on a linear shaping filter

$$dQ = [-(\overline{c} + \tilde{c})E + \overline{N} + \tilde{N}]dt\,, \tag{1}$$

where E is evaporation from the surface of the river watershed; $c = \overline{c} + \tilde{c}$ и $N = \overline{N} + \tilde{N}$ ($c = 1/k\tau$; $N = X/\tau$; k – is evaporation coefficient; τ – is relaxation time of the river watershed; X – is intensity of precipitation; $\overline{c}$, $\overline{N}$ – are mathematical expectations; $\tilde{c}$, $\tilde{N}$ – are white Gaussian noises with $G_{\tilde{c}}$ and $G_{\tilde{N}}$ intensities that are correlated with the mutual intensity $G_{\tilde{c}\tilde{N}}$).

Equation (1) is statistically equivalent to the Fokker–Planck–Kolmogorov model, which describes the Markovian evolution of the process of the long-term evaporation probability density formation. This model is approximated by a system of four differential equations for the initial moments m_i :

$$\begin{aligned}
dm_1/dt &= -(\overline{c} - 0{,}5\,G_{\tilde{c}})m_1 + \overline{N} - 0{,}5\,G_{\tilde{c}\tilde{N}};\\
dm_2/dt &= -2\,(\overline{c} - G_{\tilde{c}})m_2 + 2\overline{N}m_1 - 3\,G_{\tilde{c}\tilde{N}}m_1 + G_{\tilde{N}};\\
dm_3/dt &= -3\,(\overline{c} - 1{,}5\,G_{\tilde{c}})m_3 + 3\overline{N}m_2 - 7{,}5\,G_{\tilde{c}\tilde{N}}m_2 + 3G_{\tilde{N}}m_1;\\
dm_4/dt &= -4\,(\overline{c} - 2\,G_{\tilde{c}})m_4 + 4\overline{N}m_3 - 4\cdot 3{,}5\,G_{\tilde{c}\tilde{N}}m_3 + 6G_{\tilde{N}}m_2.
\end{aligned} \tag{2}$$

Algorithm for use of the system (2) boils down to two stages: 1) parameterization (finding $\overline{c}$, $G_{\tilde{c}}$, $G_{\tilde{N}}$, $G_{\tilde{c}\tilde{N}}$) on the basis of known moments m_i , calculated from the known series of evaporation found by empirical formulas for annual evaporation recommended by the World Meteorological Organization [4, 5] – the inverse problem; 2) introduction to a parameterized model of scenario characteristics of climate and evaluation the numerical values of the expected moments of probability distributions of evaporation required for plotting forecast (scenarios) maps of the distribution of its norm $\overline{E}$, variation *Cv* and *Cs* skewness coefficients on the

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territory – is the direct problem. A peculiarity of the system (2) is that low-order moments do not depend on the high-order ones, which means that "dropping" the latter leaves the equation system closed. This opens the possibility for the substantial simplification of the concerned model for vaporization (as in the case of river runoff [1]).

III. Results and Discussion

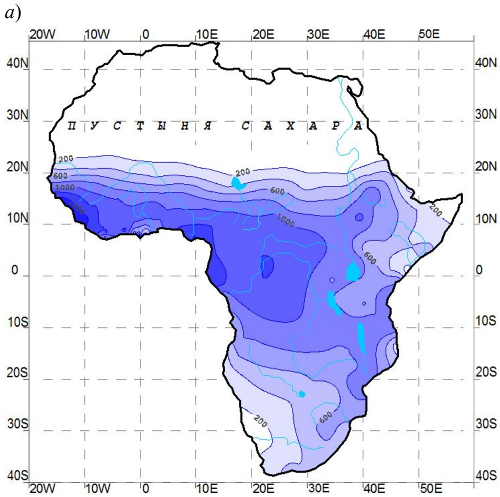
Fig. 1 presents spatial distribution maps of norm on the African territory (*a*) as example and the variation coefficient (*b*) the total annual evaporation, as well as deviations of the forecasting norms from the actual ones (*c*) for Commit scenario (2040–2069).

Table 1 shows the actual estimates and change of scenario estimates of the temperature, precipitation and evaporation for the four scenarios for 2040–2069.

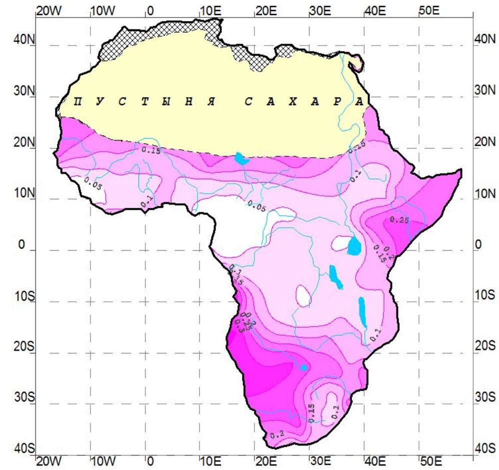
Table 1. The average values of hydrometeorological characteristics on the territory of Africa

Parameter	Actual estimates (1951–1990)	Change in scenario estimate (2040–2069) compared to the actual estimate, Δ,%			
		Commit	*SRA1B*	*SRA2*	*SRB1*
T, °C	23.7	6.7	14.0	14.2	11.6
X, mm	1049	13.1	9.5	13.8	10.2
E, mm	797	10.2	11.7	13.0	10.6
k_E	0.84	–1.7	1.4	0.2	0.4
C_v	0.17	–20.7	–13.5	–15.1	–12.5

a)



b)



c)

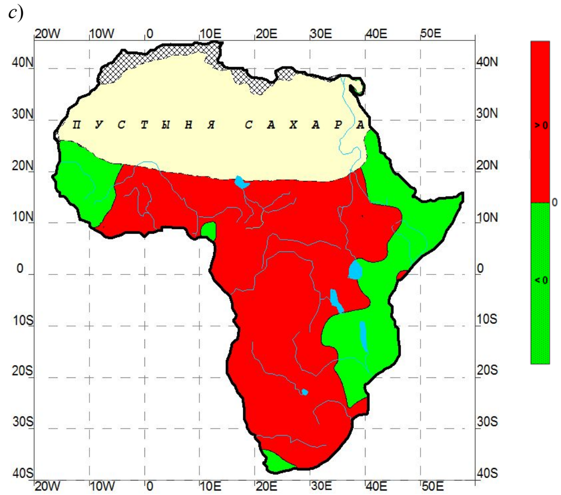
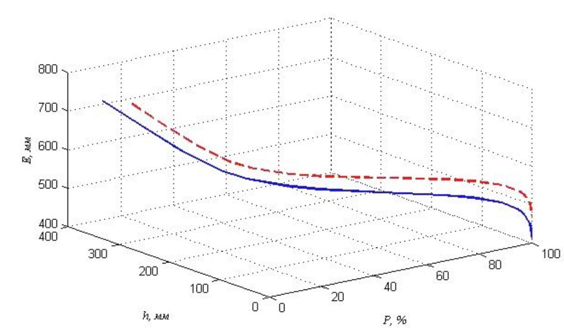


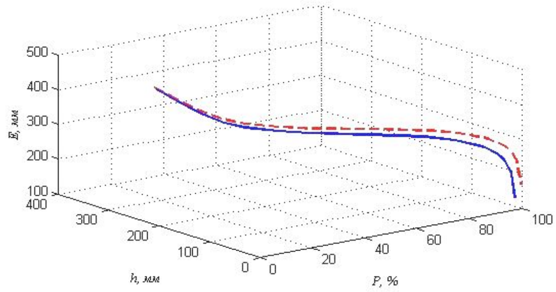
Fig. 1. Distribution of the actual (*a*, *b*) and forecast (c) parameters of evaporation in Africa.

The building design uses probability curves of runoff and evaporation, which are plotted on the first three moments in the framework of the family of Pearson distributions, but rather on the calculated parameters: norm, coefficients of variation and skewness. Joint visual representation of these probability curves can be achieved by using one-dimensional manifolds in three-dimensional space (probability *P*, evaporation *E*, runoff *Q*). Fig. 2 shows examples of such manifolds for river watersheds in Africa, Iran and Russia.

a)



b)



c)

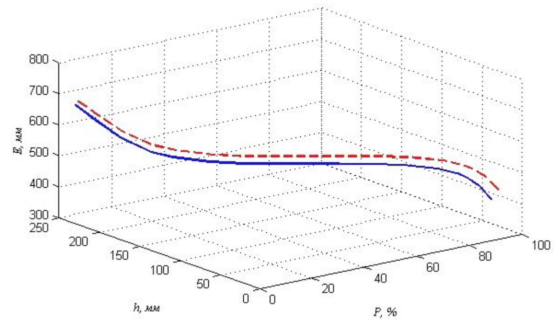


Fig 2. One-dimensional probability manifolds: *a*) Klip – Delangesdrift (ZA, Africa); *b*) Sefidrood – Graguni (Iran); *c*) Syzranka – Repyevka (Russia): — – actual curve, – – – – forecast curve according to Commit scenario for 2040–2069.

Such probability manifolds were built for virtually all climatic zones of the Globe. It was found that there is a reduction of $\gamma_{X P\%} = Q_{P\%} / E_{P\%}$ factor in proportion to the growth of probability in most cases, i.e. in proportion to decreasing of evaporation the selective precipitation value increases. Consequently, the proportion of evaporation in the annual balance increases in the dry years compared to the runoff. Table 2 shows the sample data to support this conclusion.

Table 2. The variation of $\gamma_{X P\%}$ coefficient, depending on the resources of the river watershed $X_{P\%}$

Number of years of observation	Area of watershed, km2	$\gamma_{X 20\%}$	$\gamma_{X 50\%}$	$\gamma_{X 80\%}$
River – station – country – climate zone				
Sok – Surgut st. – Russian Federation – broad-leafed steppes and meadow steppes of moderate continental climate				
49	4730	0.31	0.26	0.22
Samara – Elshanka st.– Russian Federation – steppe of temperate continental climate				
49	22800	0.15	0.12	0.09
Ufa – Krasnoufimsk st. – Russian Federation – mixed (coniferous and deciduous) forests of the temperate continental climate				
49	14200	0.66	0.56	0.50
Cheptsa – Polom st. – Russian Federation – coniferous taiga temperate continental climate				
49	5930	0.55	0.49	0.41
Sefidrood – Graguni – Iran – semi-desert and desert sharply continental climate				
34	19600	0.17	0.13	0.10
Karun – Durod – Iran – dry steppe, woodland and shrubs continental climate				
25	3400	0.66	0.64	0.63
Klip – Delangesdrift – South Africa – seasonally wet mixed (deciduous evergreen) tropical forests				
40	4150	0.12	0.06	0.03
Doring – Elands Drift-Aspoort – South Africa – woodlands, savannas and shrubs eastern part of the continent subtropical zone				
40	6890	0.16	0.11	0.06
Incomati – Hooggenoeg – South Africa – seasonally wet mixed (deciduous evergreen) tropical forests				
40	5540	0.13	0.10	0.08

Conclusions

Thus, this article obtains the following results.

1. It is shown that the methodology for long-term estimates of the runoff probability characteristics under climate change conditions can also be used for similar long-term estimates of evaporation. This is related to the fact that the probability distributions of evaporation, as well as that of runoff, belong to the family of K. Pearson distributions, and thus, the model of linear shaping filter is applicable to describe their evolution.
2. The possibility of effective joint visualization of actual and forecast probability curves of runoff and evaporation using one-dimensional manifold in the space of probability – runoff – evaporation is revealed.
3. The phenomenon of increase in the selective value of evaporation in proportion to the decreasing in precipitation, which occurs in virtually all climatic zones of the world.

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